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FLOWPATH OPTIMIZATION FOR BRUCE "A" STEAM GENERATOR CHEMICAL CLEANING

Report No. 86-350-K

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ABSTRACT

Both Bruce "A" and Pickering "A" steam generators have very hard tubesheet deposits composed mostly of magnetite and copper. Tube/tubesheet crevice corrosion and tube degradation may occur if these deposits are not removed from the steam generator. A program was undertaken by Chemical Research to evaluate and optimize a chemical cleaning process for tube sheet deposit removal from Bruce "A" steam generators. A flowpath optimization test program was developed to assess the amount of sludge/solvent contact and solvent mixing in the tube bundle at the tubesheet during a chemical clean at Bruce "A". The solvent inlet/outlet configuration (using steam generator blowdown lines), solvent depth and flow rate were optimized using a full scale mockup of a half sector of a Bruce "A" tubesheet. A simulated "sludge pile" was inserted for some tests. Flows through the tube bundle during a physical simulation of a chemical clean were effectively demonstrated. Solvent recirculation was superior to a steam generator fill and drain for maximizing flow over the sludge pile. The inlet/outlet configurations in decreasing order of effectiveness were; boxheader as inlet, and two peripheral blowdowns farthest from the boxheader as outlets; all peripheral blowdowns as outlets and the boxheader as inlet; and all peripheral blowdowns as inlets and the box header as outlet. The optimum depth was the minimum at which the sludge pile remained submerged, allowing for a margin of assurance. The optimum flow rate was the highest flowrate feasible with respect to engineering constraints.

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EXECUTIVE SUMMARY

FLOWPATH OPTIMIZATION FOR BRUCE 'A' STEAM GENERATOR CHEMICAL CLEANING

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Chemical Research Department

Both Bruce "A" and Pickering "A" steam generators have very hard tubesheet deposits. These deposits are composed mostly of magnetite and copper with varying amounts of impurities. Under normal operating heat fluxes in the steam generator, the feedwater contaminant concentrations in the sludge pile may increase to values orders of magnitude above bulk levels. Attack of the I-600 tubing by these contaminants may ultimately result in tube leaks. Tube/tubesheet crevice corrosion and tube degradation may occur if these deposits are not removed from the steam generator.

Chemical Research undertook an extensive chemical cleaning program funded by TTSD to develop a working process for chemically cleaning Bruce "A" steam generators. Flowpath optimization studies discussed in this report are one part of the program.

The success of a chemical clean depends on how well the sludge dissolves in the solvent and how well insoluble components of the sludge (if any) are broken up and entrained in the solvent. The dissolution rate depends on diffusion rates of solvent and dissolved sludge within the sludge pile. The concentration of dissolved sludge at the sludge surface should be minimized and be close to the concentration of dissolved sludge in the bulk solution. This is ensured by good mixing of the solvent in the steam generator.

One concern about chemically cleaning steam generator tubesheets is whether there is adequate solvent/sludge contact and mixing in the tube bundle. The blowdown lines must be used as the solvent inlet/outlet since there are no readily accessible hand holes into the secondary side of the steam generator close to the tubesheet.

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The test program was developed to assess the amount of sludge/solvent contact and solvent mixing in the tube bundle during a chemical clean. The solvent inlet/outlet configuration (using the steam generator blowdown lines), solvent depth and flow rate were optimized using a full scale mockup of a half sector of a Bruce "A" tubesheet. The effects of flow rate, solvent inlet/outlet configuration, solvent depth in the steam generator, and fill/drain versus recirculation modes of operation were studied. A "sludge pile" was inserted for some tests to determine any effects on flow patterns.

Tests in the Flow Visualization Loop effectively demonstrated flows through the tube bundle during a physical simulation of a chemical clean. Solvent recirculation was superior to fill/drain for maximizing flow over the sludge pile. It is possible to get good solvent circulation over the sludge pile using the blowdown lines as inlets and outlets.

The following parameters were optimized for a Bruce "A" steam generator chemical clean:

a. Optimum Inlet/Outlet Configuration

The optimum inlet/outlet configuration uses the boxheader as the solvent inlet to the steam generator and the two peripheral blowdowns farthest from the boxheader on each side of the box header as outlets. Blocking of the other peripheral blowdowns to prevent solvent flow through them is necessary. If this is not feasible, then it is recommended that all peripheral blowdowns be used as solvent outlets.

b. Optimum Water Level

The optimum water level in the steam generator is the minimum level at which the sludge pile remains submerged. The depth should be increased however to build in a margin of assurance. For a 15 cm sludge pile, a 20 cm solvent depth is suggested. The minimum water level is limited by cavitation at the outlet blow downs.

c. Optimum Flowrate

The optimum flowrate appears to be the highest possible flowrate given equipment limitations and any limitations on flow defined by erosion-corrosion tests. A flowrate of 6 to 11 L/s would be sufficient. At a solvent level in the steam generator of 20 cm, a minimum flowrate of 8.8 L/s is recommended if all peripheral blowdowns must be used as outlets. This should give a velocity of about 4 cm/s over the sludge pile.

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To: Mr. B. Montford
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FLOWPATH OPTIMIZATION FOR BRUCE "A"
STEAM GENERATOR CHEMICAL CLEANING

1. INTRODUCTION

1.1 Background

Both Bruce "A" and Pickering "A" steam generators have very hard tubesheet deposits. These deposits are composed mostly of magnetite and copper with varying amounts of impurities/1,2/. Under normal operating heat fluxes in the steam generator, the feedwater contaminant concentrations in the sludge pile may increase to values orders of magnitude above bulk levels. Attack of the I-600 tubing by these contaminants may ultimately result in tube leaks. If not removed from the steam generator, these deposits may lead to tube/tubesheet crevice corrosion and tube degradation.

1.2 Chemical Cleaning

Chemical Research undertook an extensive chemical cleaning program funded by TTSD to develop a working process for chemically cleaning Bruce steam generators. The Flowpath Optimization Studies discussed in this report are one part of the program.

The success of a chemical clean ultimately depends on how well the sludge dissolves in the solvent and how well insoluble parts of the sludge (if any) are broken up and entrained in the solvent. The limiting factor in the sludge dissolution process is unknown. It could be chemical kinetics, mass transfer rate from sludge to solvent within the sludge pile, or diffusion of dissolved metals out of the sludge pile into the bulk solution. The last factor, and to some extent, the second factor is proportional to the difference in solute concentration between the sludge pile and the sludge pile-bulk solution interface (Fick's First Law of Diffusion). Thus the concentration of dissolved sludge at the sludge pile surface should be minimized and be close

to the bulk value. This is ensured by good mixing of the solvent in the steam generator.

One concern about chemically cleaning steam generator tubesheets is whether there is adequate solvent/sludge contact and mixing in the tube bundle. There are design-imposed restrictions on the possible solvent flow paths. The blowdown lines must be used as the solvent inlet/outlet since there are no readily accessible hand holes into the secondary side of the steam generator close to the tubesheet.

The test program was developed to assess the amount of sludge/ solvent contact and solvent mixing in the tube bundle during a chemical clean.

2. PURPOSE

The purpose of this study was to optimize the blowdown inlet/ outlet configuration, solvent depth and flow rate for chemical cleaning using the existing arrangement of blowdowns at Bruce "A".

A full scale mockup of a half sector of a Bruce "A" tubesheet was built for these tests. The effects of flow rate, solvent inlet/ outlet configuration, solvent depth in the steam generator, and fill/drain versus recirculation modes of operation were studied. A simulated sludge pile was inserted for some tests to determine any effects on flow patterns.

3. BRUCE "A" STEAM GENERATORS

A Bruce "A" steam generator (Figure 1), 221 cm in diameter, contains 4600 1.27 cm I-600 tubes in a triangular pitch of 20.32 mm. The maximum width of the tube bundle perpendicular to the boxheader is 98.7 cm. There are twelve 1 inch ID (2.54 cm) peripheral blowdowns staggered equidistantly around the inside perimeter of the steam generator shell. They terminate 2.5 cm above the surface of the tubesheet. Two 1.5 inch ID (3.8 cm) diametral blowdown lines, at either end of the tube free lane are joined together by the boxheader. The peripheral blowdowns are isolated from the diametral blowdowns but not from each other. Each side of the boxheader contains 114 3/16 inch (0.48 cm) diameter holes approximately 6.3 mm from the tubesheet surface.

These blowdowns are normally used during operation for purging the steam generator of particulates which have settled on the tubesheet and are also used to flush the steam generator of water of undesirable chemistry.

4. EQUIPMENT

4.1 Steam Generator Tubesheet Mockup

a. Design

A steam generator tubesheet mockup (Figures 2 and 3) was constructed. An aluminum mockup of a half sector of a Bruce tubesheet built originally for TTSD Bruce "A" eddy current probe tests was used. Polyvinyl chloride (PVC)

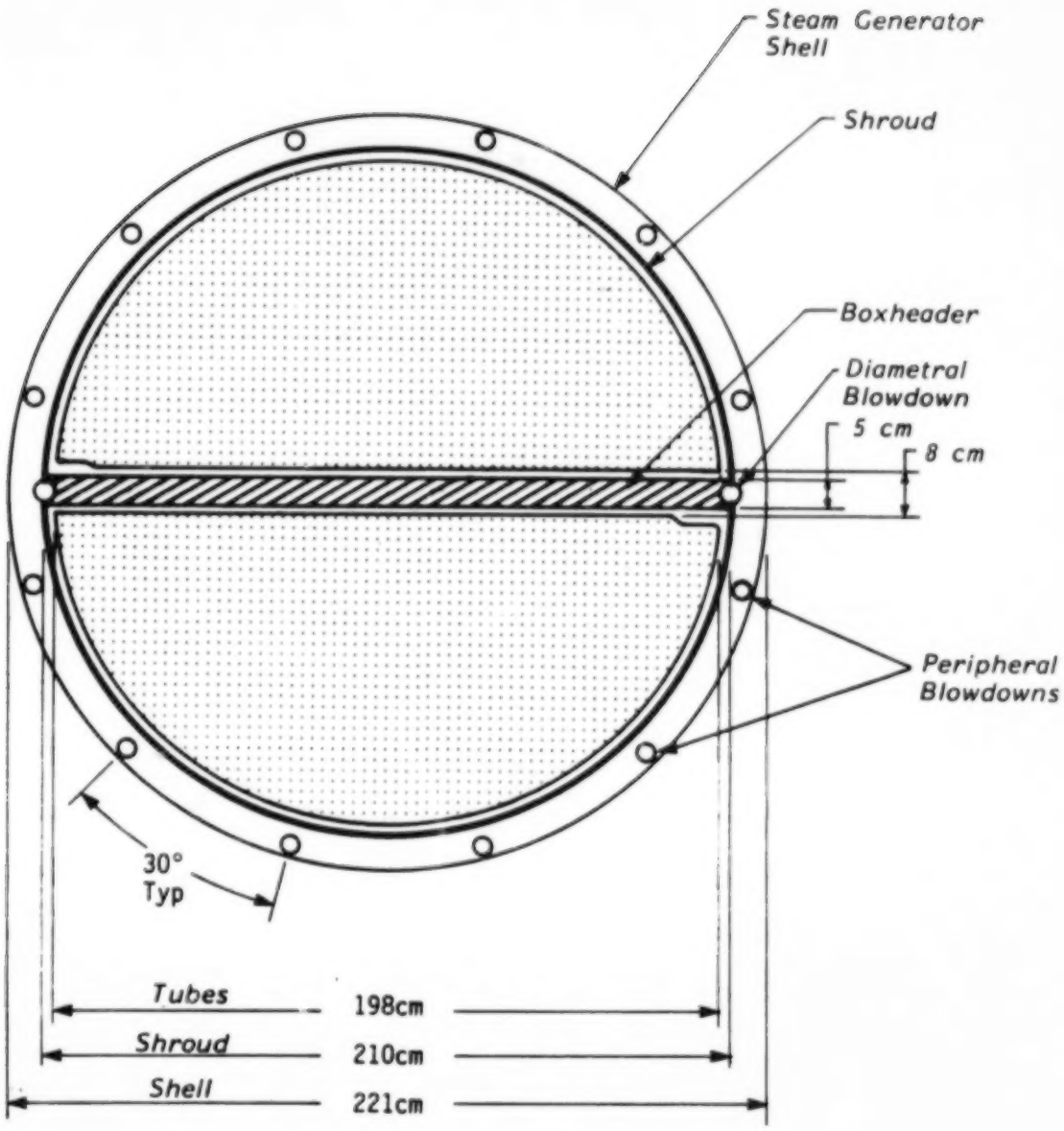


FIGURE 1
BRUCE 'A' STEAM GENERATOR TUBESHEET

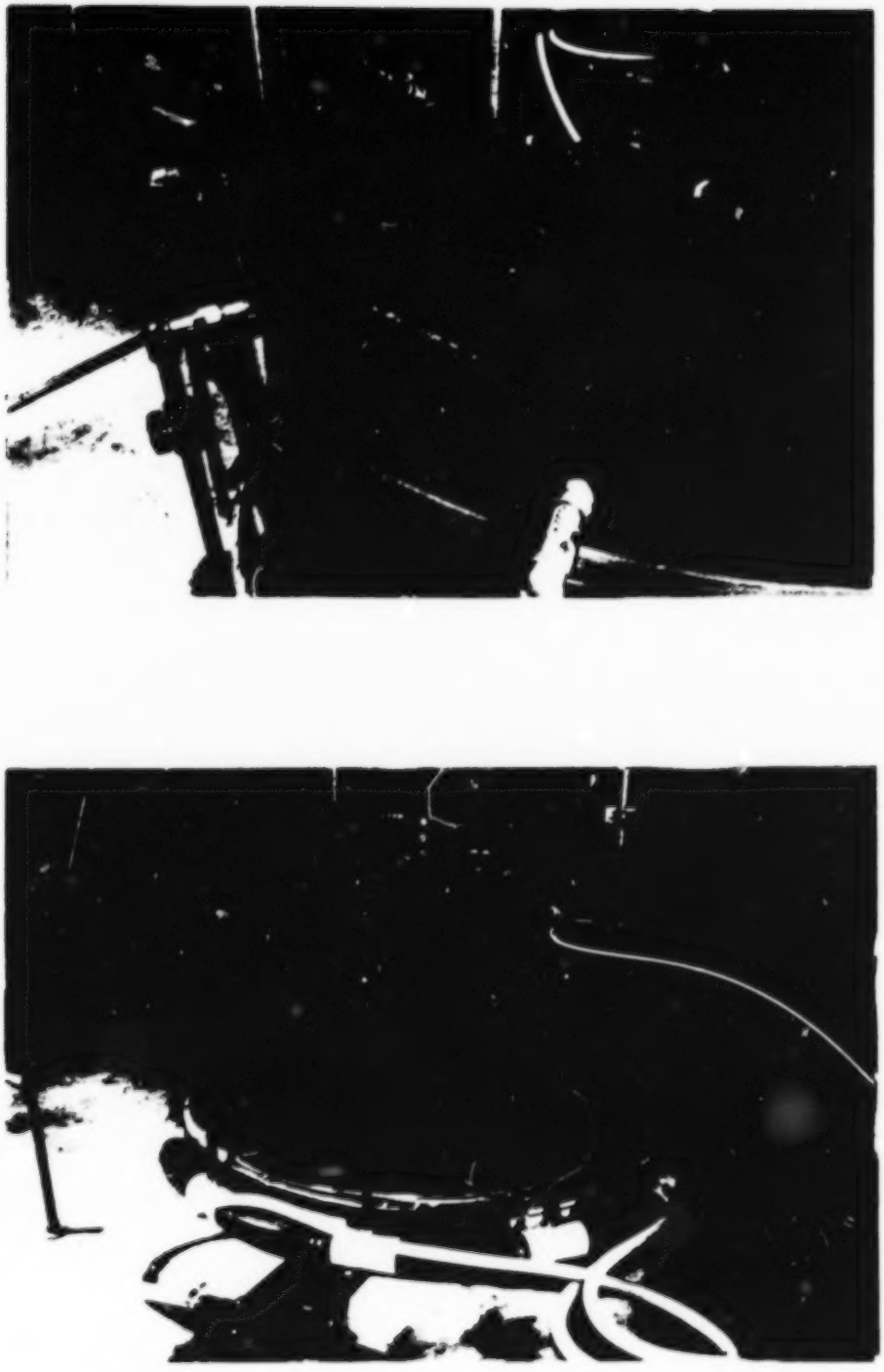
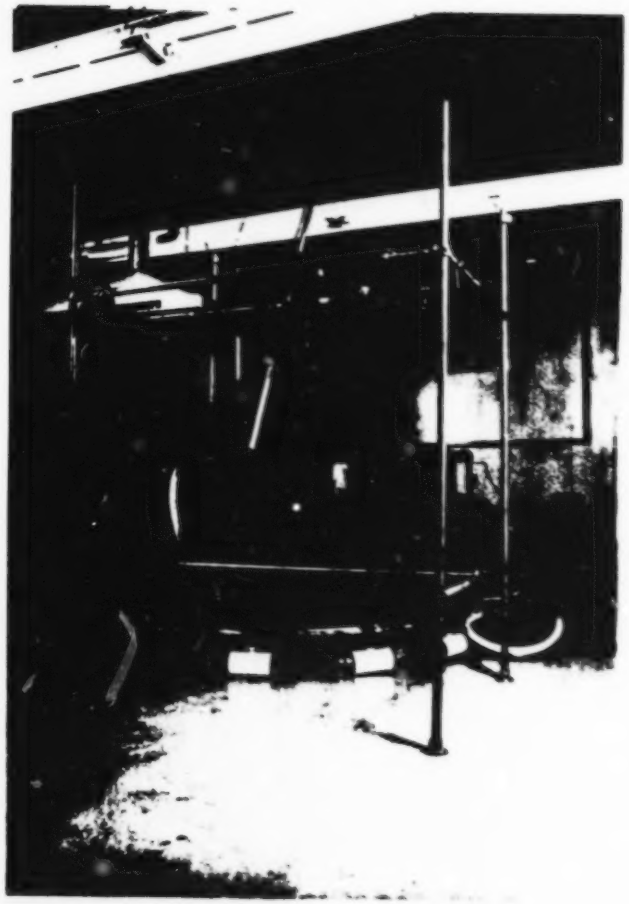


FIGURE 2
STEAM GENERATOR TUBESHEET MOCKUP



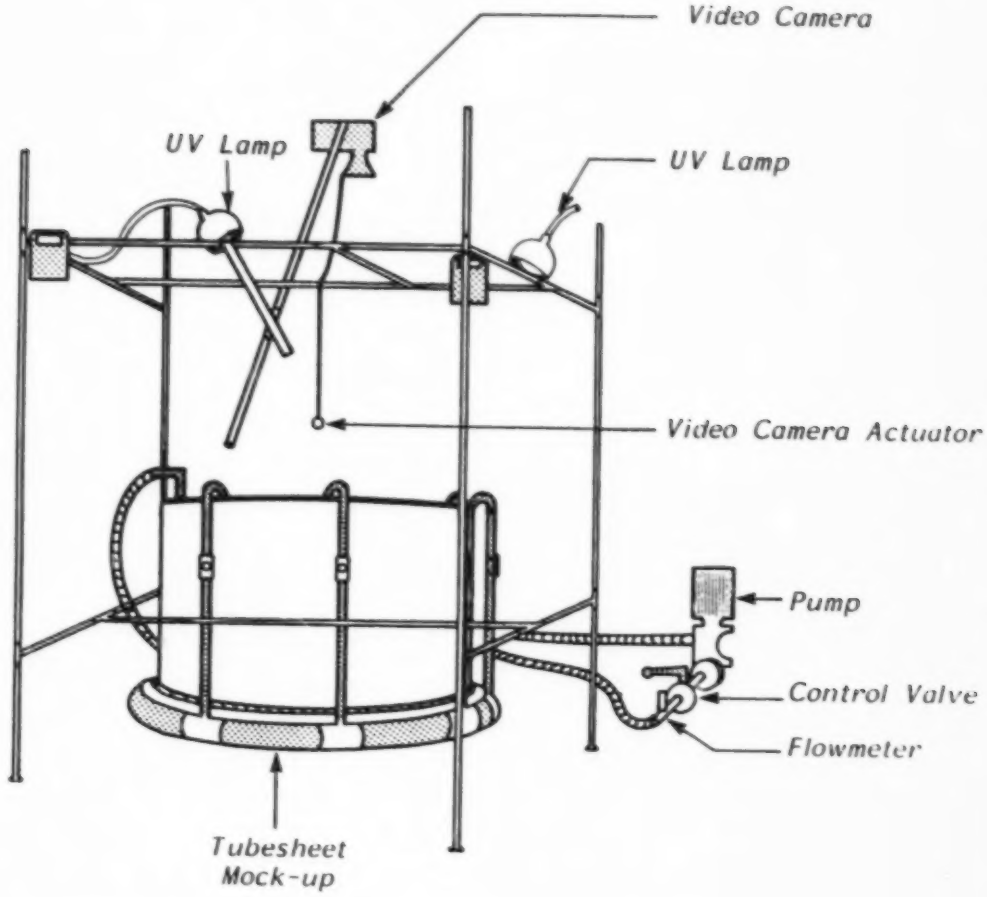


FIGURE 3
FLOW VISUALIZATION LOOP

walls were built and then fastened to the tube-sheet to form a tank. Two PVC diametral and six peripheral blowdowns were inserted.

The peripheral blowdowns could be individually isolated so that any combination could be used. The diametral blowdowns were isolated from the peripherals as they are at Bruce. Since the mockup was a half sector of the tubesheet, the diametral blowdown mockup consisted of one half of each of the diametral blowdowns and the boxheader.

The shroud was not included because the size of the tubesheet mockup was too small to accommodate it. The shroud is not expected to greatly affect the flow path during a clean since it is solid only to about 43 cm from the tubesheet.

Tube stubs, 5 cm long, protruded from the tubesheet and were extended to 30 cm with PVC rods which were friction-fitted into the tubes. Half of these rods (a quarter sector) were later cut to approximately 15 cm in order to view dye in the tube bundle at lower water levels.

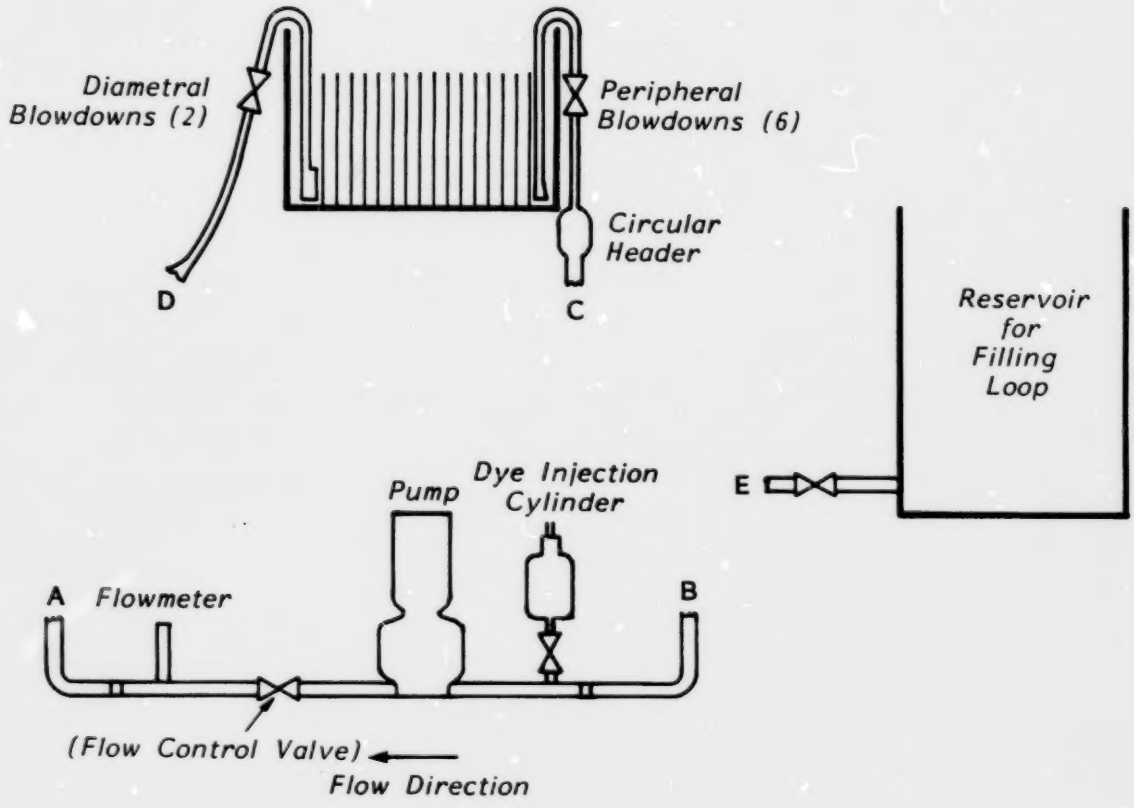
b. Operation

Figures 4 and 5 show a diagram of the loop and photographs of its components. The loop operated in both fill/drain and recirculation modes. A 7.5 HP centrifugal pump was used. Flexible plastic hoses connected the pump to the tubesheet mockup with quick-connect couplings. A CALQFLO pitot-tube flowmeter was placed immediately downstream of the pump. Maximum flow in the loop was 5.4 L/s. A 50 mL dye injection cylinder was placed immediately upstream of the pump.

4.2 Flow Visualization

Flow patterns were made visible by injecting a dye. Several dyes were tested to obtain the best results for visualization of the flow; conventional (food dye), luminol (a chemiluminescent compound), and fluorescein (diluted in water or alcohol). The conventional dye was almost invisible against the gray PVC, and the luminol was short lived requiring the addition of basic solution which was corrosive to the aluminum tubesheet. The fluorescein dye, diluted in water and activated by uv lamps placed from 2 to 3 m above the tubesheet gave the best indication of flow and was used for all tests.

The dye was injected into the water by one of two methods; directly into the tank at different points inside and beside the tube bundle on the surface of the water or at the tubesheet surface, or through the injection cylinder. A 10 mL syringe inserted into a length of small diameter steel tubing was used for the direct injections. Dye injected through the cylinder (Figure 5) would emerge as a front from those blowdown lines which were set up as inlets. Figures 6 and 7 show the flow visualization and dye injection method.



Loop Connections for Different Operating Modes

A,B,C,D,E *are quick-connect fittings.*

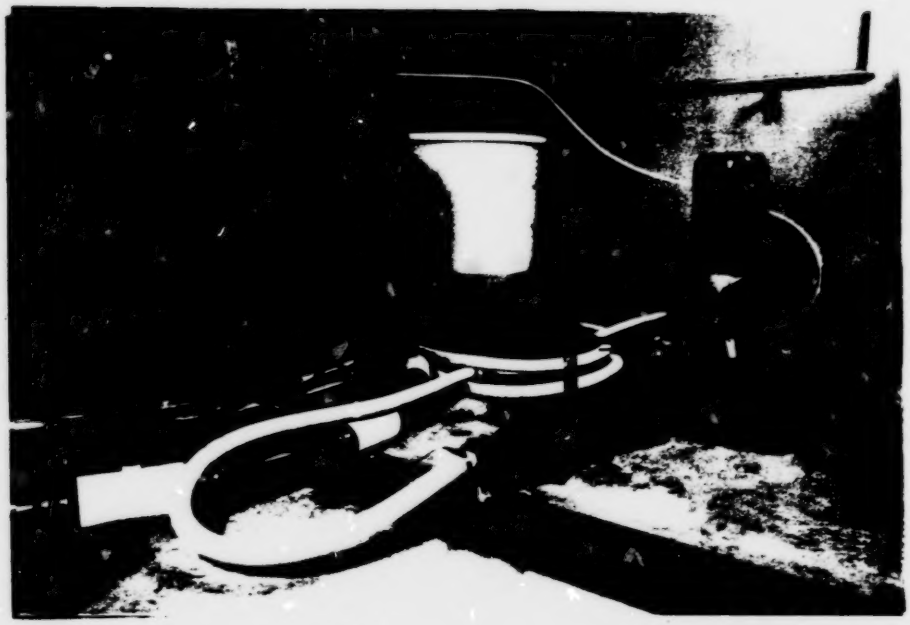
Recirculation: **AD:BC** *or* **AC:BD** *connections*

Fill: **EB:A(D+C)**, *or* **EB:AD**, *or* **EB:AC** *connections*

Drain: **(D+C)B**, *or* **DB**, *or* **CB** *connections*

FIGURE 4

DIAGRAM OF FLOW VISUALIZATION LOOP



1 *Reservoir*
2 *Dye Injection Cylinder*
3 *Pump*
4 *Flow Control Valve*
5 *Flow Meter*
6 *Tubesheet Mockup*

1 *Pump*
2 *Dye Injection Cylinder*

FIGURE 5

LOOP COMPONENTS

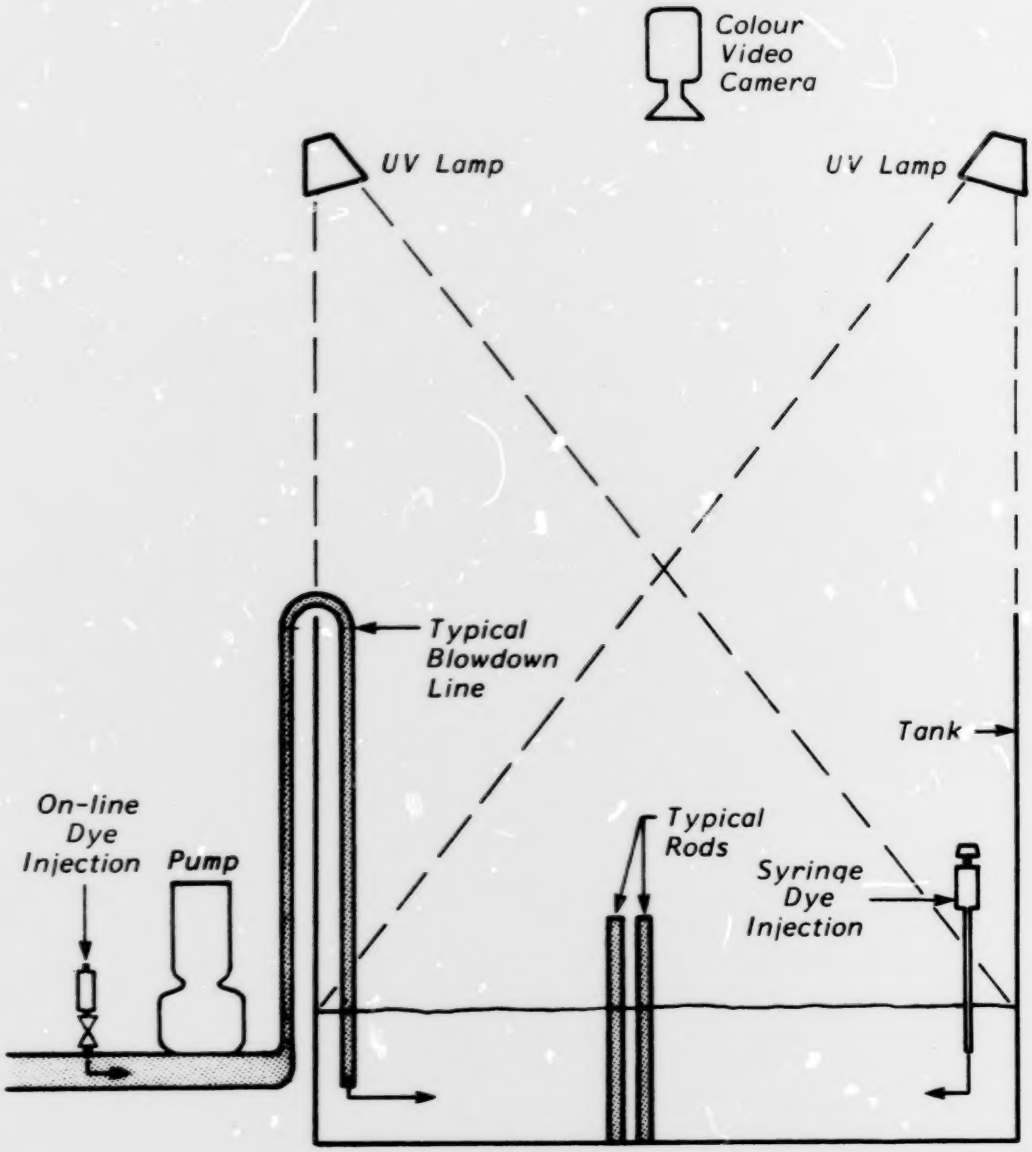


FIGURE 6

SCHEMATIC OF DYE VISUALIZATION OF FLOW

FIGURE 7
DYE INJECTION VIA SYRINGE

4.3 Sludge Pile

Figure 8 shows a sludge pile built to simulate the dimensions of a Bruce NGS sludge pile as determined by ECI measurements/3/. Strips of polyester batting were pressed down between the tubes. This formed an immovable barrier to flow. Sand or sludge was not used because it may have moved with the flow and decreased the visibility of the dye.

5. EXPERIMENTAL

All experiments were videotaped on VHS using a hand-held camera mounted about 1 m above the tube sheet for some tests and about 4 m for other tests. For each of the fill/drain and recirculation modes (see Figure 4), parameters were varied as shown in Table 1, which also summarizes the inlet/outlet configurations tested. These are shown schematically in Figure 9.

TABLE 1 - Experimental Parameters

Flow Rate 1, 1.5, 3.0, 5.4 L/s
Water Depth 7.7, 15.3, 30.5 cm

Inlet/Outlet Configuration

Designation	Boxheader	All Peripherals	2 Peripherals
B1	inlet	outlet	
B2	inlet		outlet
AB	outlet	inlet	
2B	outlet		inlet

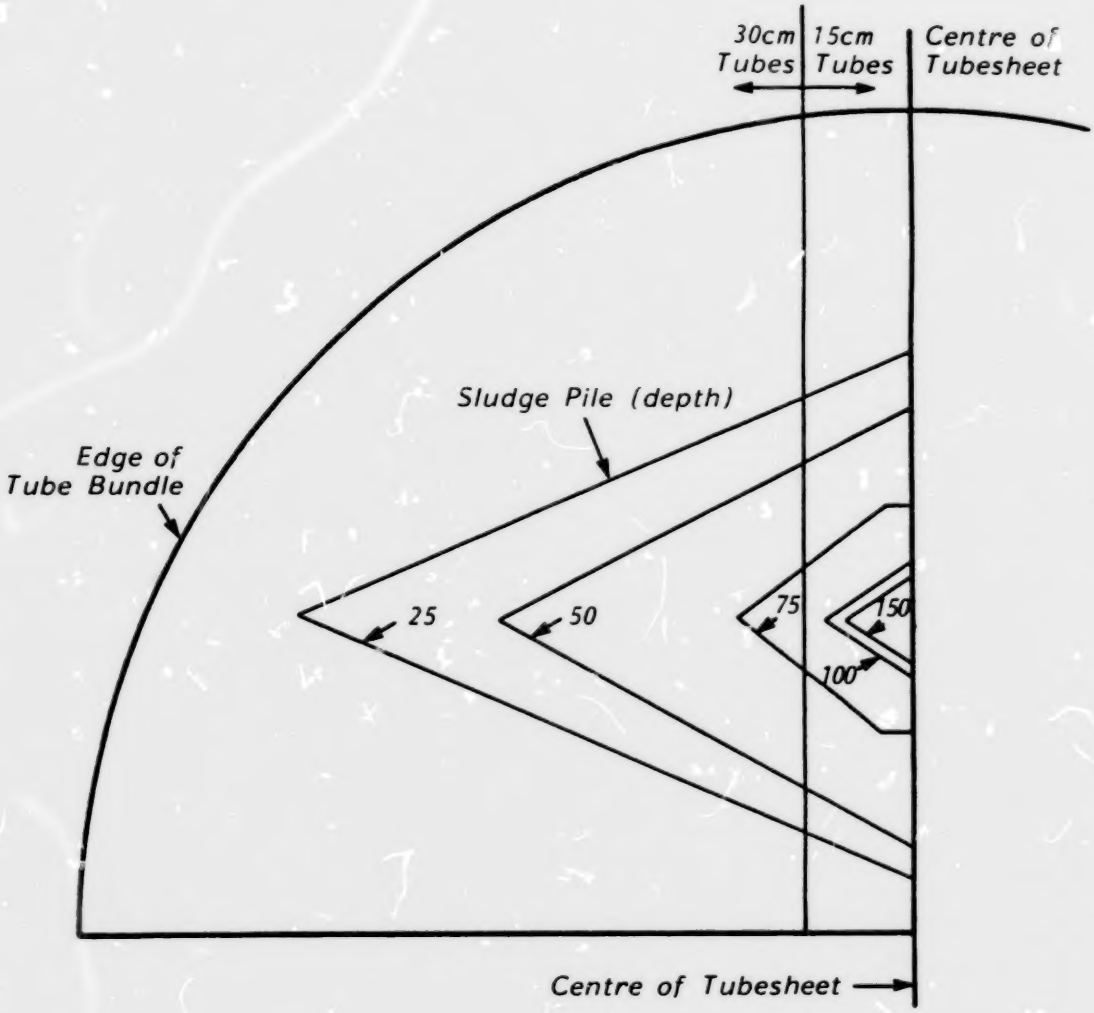
A total of 92 experiments were performed. Comments from observations of videotapes on fill/drain tests and some recirculation tests were recorded. For recirculation tests, the time for the dye front to travel from the boxheader to the edge of the tube bundle farthest from the boxheader or vice versa (Figure 10) was measured from the videotapes.

A 6-1/2 minute videotape (3/4 inch format) was made from the videotaped data to illustrate the findings and conclusions and is available on loan from the author upon request.

6. RESULTS AND DISCUSSION

6.1 Fill/Drain Experiments

Tests were performed to assess the amount of flow in the region of the sludge pile during partial filling and subsequent draining of the steam generator

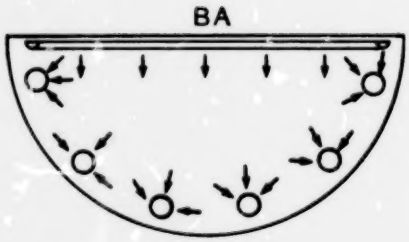


Note:

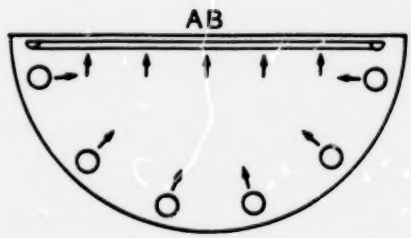
All dimensions in mm unless otherwise specified

FIGURE 8

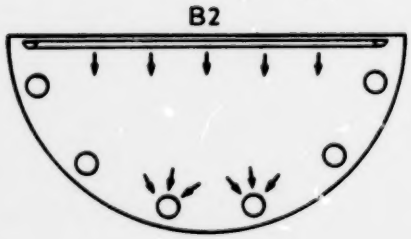
TUBESHEET 'SLUDGE' PILE MOCKUP



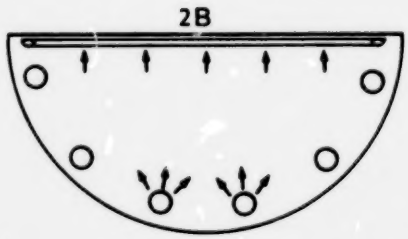
Inlet: Boxheader
Outlet: All Peripherals



Inlet: All Peripherals
Outlet: Boxheader



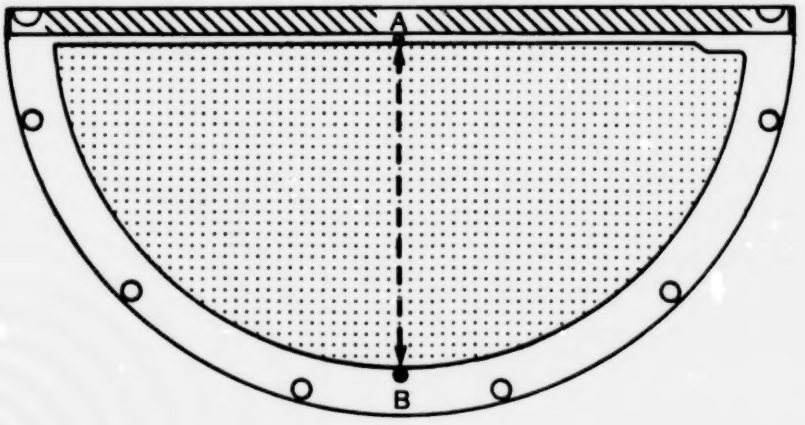
Inlet: Boxheader
Outlet: 2 Farthest Peripherals



Inlet: 2 Farthest Peripherals
Outlet: Boxheader

FIGURE 9

INLET/OUTLET CONFIGURATIONS



Velocity measured by recording time for dye front to travel from A to B or vice versa

FIGURE 10

METHOD OF VELOCITY MEASUREMENT ACROSS TUBESHEET

mockup. Results from these experiments showed that movement of the dye into the sludge region was ineffective. At the tested flow rates of 1 to 3 L/s, most of the flow tended to be around the periphery with minimal flow and turbulent penetration into the tube bundle. During filling, turbulence was observed mainly at the inlets into the tank. Slow eddies were visible in other parts of the tube bundle periphery depending on the flow. Flow elsewhere appeared laminar and, deep inside the tube bundle, virtually stagnant. With the boxheader as the inlet there was turbulent penetration into the tube bundle for about 30 cm from the boxheader. The amount of turbulence (if present) appeared to be inversely proportional to the water levels in the tank.

It is recommended that the fill/drain method not be used during a chemical clean because there is very little solvent circulation in the region of the sludge pile.

6.2 Recirculation Experiments

a. Effect of Depth

Experiments performed at different depths showed that velocities inside the tube bundle increased with decreasing depth for all flowrates and inlet/outlet configurations. This is illustrated in Figure 11 where the average horizontal velocity measured (as shown in Figure 10) is plotted against flowrate for different inlet/outlet configurations and water levels.

All experiments without a sludge pile are represented in Figure 11. Although the full matrix would comprise 36 experiments, only 29 experiments were performed. Data could not be obtained for the B2 configuration at 5.4 L/s at all water levels because pump cavitation precluded the tests. No tests were performed at 30.5 cm water level and a flowrate of 1.5 L/s because it became difficult to assess the movement of the dye front.

The relatively flat response of velocity to a change in flowrate at a depth of 30 cm shows that at this depth, there was sufficient stratification of flow so that most of the flow occurred close to the tubesheet. Surface flow was generally minimal except at low water levels.

b. Comparison of Observed and Theoretical Velocities

The effective diameter of the tube bundle parallel to the box header was calculated in order to compare the observed velocities in the tube bundle with a corresponding theoretical "average" velocity. "Average" velocity was calculated as follows:

$$V_a = F/(L*D)$$

where: V_a = theoretical average velocity (cm/s)
F = flowrate (mL/s)
L = tank water depth (cm)
D = effective diameter (cm)

Water Level	Blowdown Configuration			
	ab	ba	b2	2b
7.7 cm	■	●	▼	▲
15.3 cm	□	○	▽	△
30.5 cm	◘	◒	×	✲

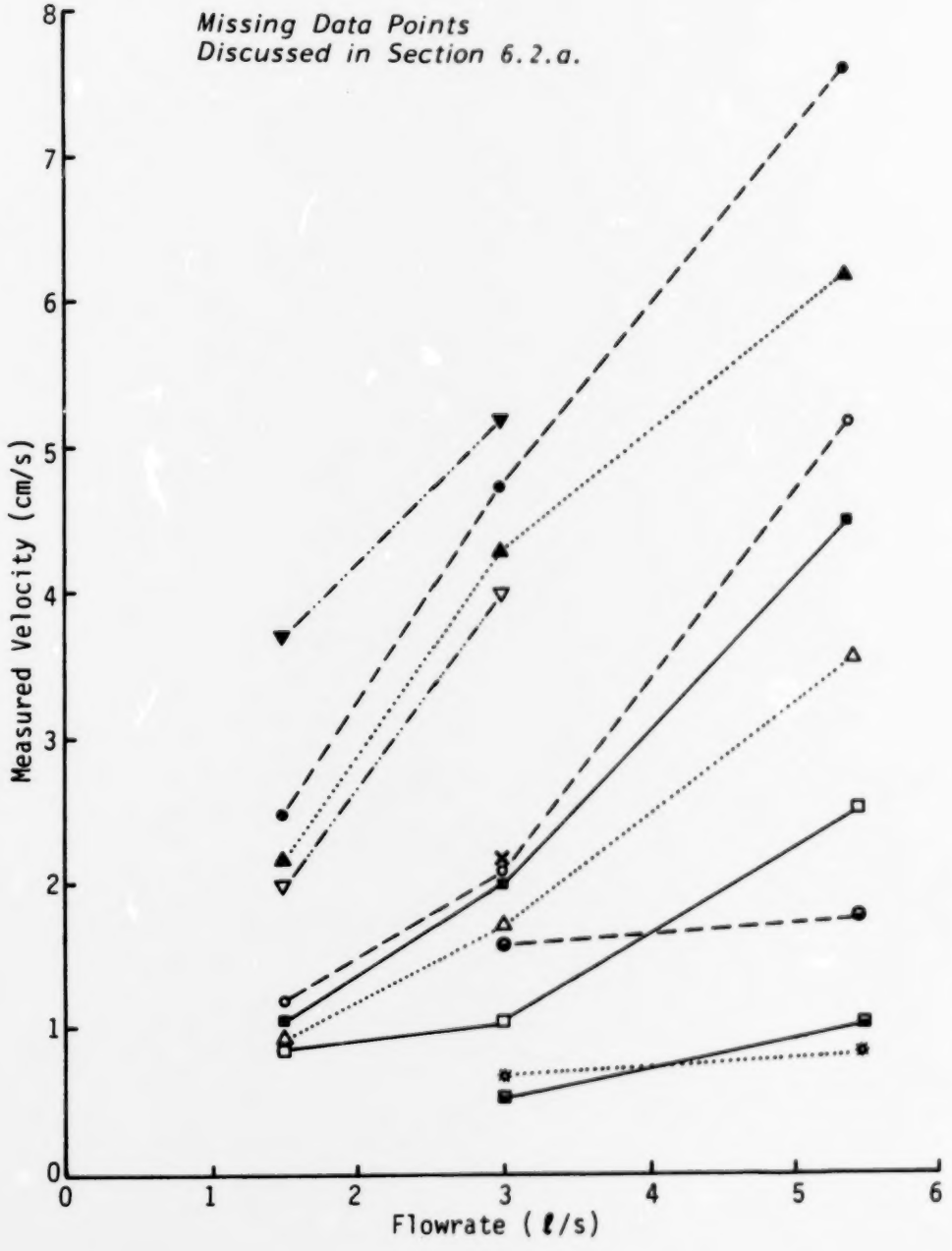


FIGURE 11

VARIATION OF VELOCITY WITH FLOWRATE FOR DIFFERENT WATER LEVELS AND BLOWDOWN INLET/OUTLET CONFIGURATIONS

The parameter D considers the flow restriction by the tubes and ignores the area between the tube bundle and tank wall. It was assumed that each row of tubes perpendicular to the boxheader behaved like a rectangular barrier of width equal to the tube diameter (Figure 12). Effective diameter was calculated as follows:

$$D = (S - T)*N$$

where: D = effective diameter
T = tube diameter = 1.27 cm
S = tube to tube spacing = 1.76 cm
N = maximum number of spaces along bundle diameter = 112

Therefore,

$$D = 54.9 \text{ cm}$$

Measured velocities most closely approach the corresponding theoretical "average" velocity for the "B2" inlet/outlet configuration as shown in Figure 13. For this configuration, the measured velocity was slightly above the corresponding theoretical "average" velocity up to a measured velocity of 4 cm/s showing a slight preferential flow across the centre of the tube sheet. At a higher measured velocity (approximately 5.2 cm/s), the measured velocity was about 70% of the corresponding theoretical velocity, showing preferential flow around the periphery of the tube bundle.

At measured velocities of about 5 cm/s, there was essentially no difference between the "B2" and "BA" configurations for which the velocities were about 70% of the theoretical average velocity. This trend would be expected to continue at measured velocities above 5 cm/s.

The worst configuration was "AB" with measured velocities of about 35% of theoretical values showing that approximately two thirds of the flow was around the periphery of the tubesheet. For the "2B" configuration, measured velocities across the tube bundle were approximately 50% of the theoretical average velocities.

c. Optimum Configuration

In order to optimize mass transfer from the sludge pile, the bulk of the solvent should flow across it. It is clear from the flowpath optimization tests that the "B2" configuration maximizes the flow through the sludge pile region up to a theoretical average velocity of 4 cm/s. At an estimated water depth of 20 cm for a Bruce steam generator chemical clean/5/, this velocity corresponds to a flowrate of 8.8 L/s in a steam generator (4.4 L/s in the mockup). However, limitations on maximum flowrate due to cavitation in the B2 configuration may favour the use of the BA configuration.

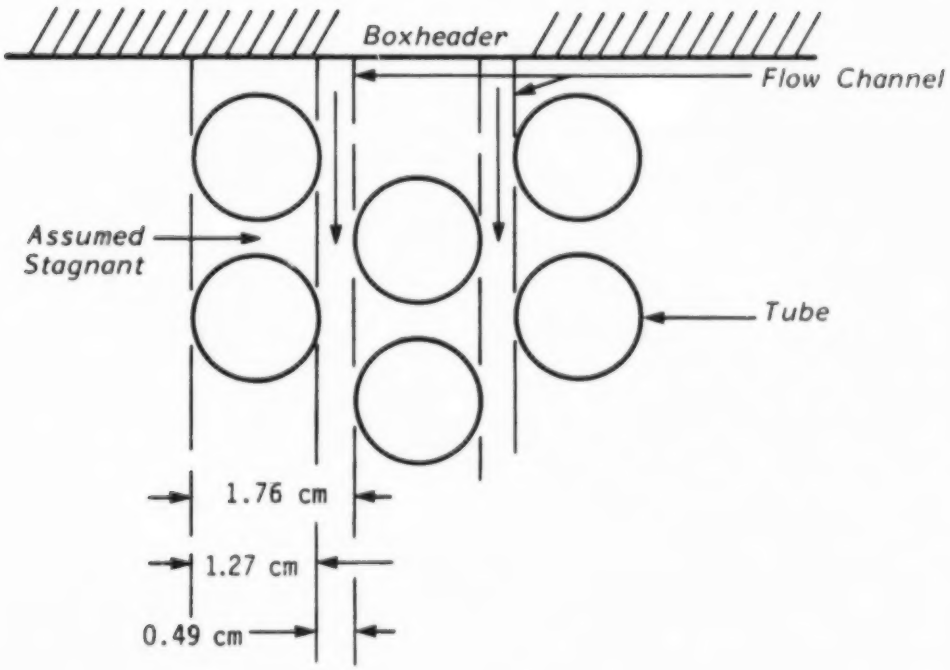


FIGURE 12

DETERMINATION OF EFFECTIVE
TUBE BUNDLE DIAMETER

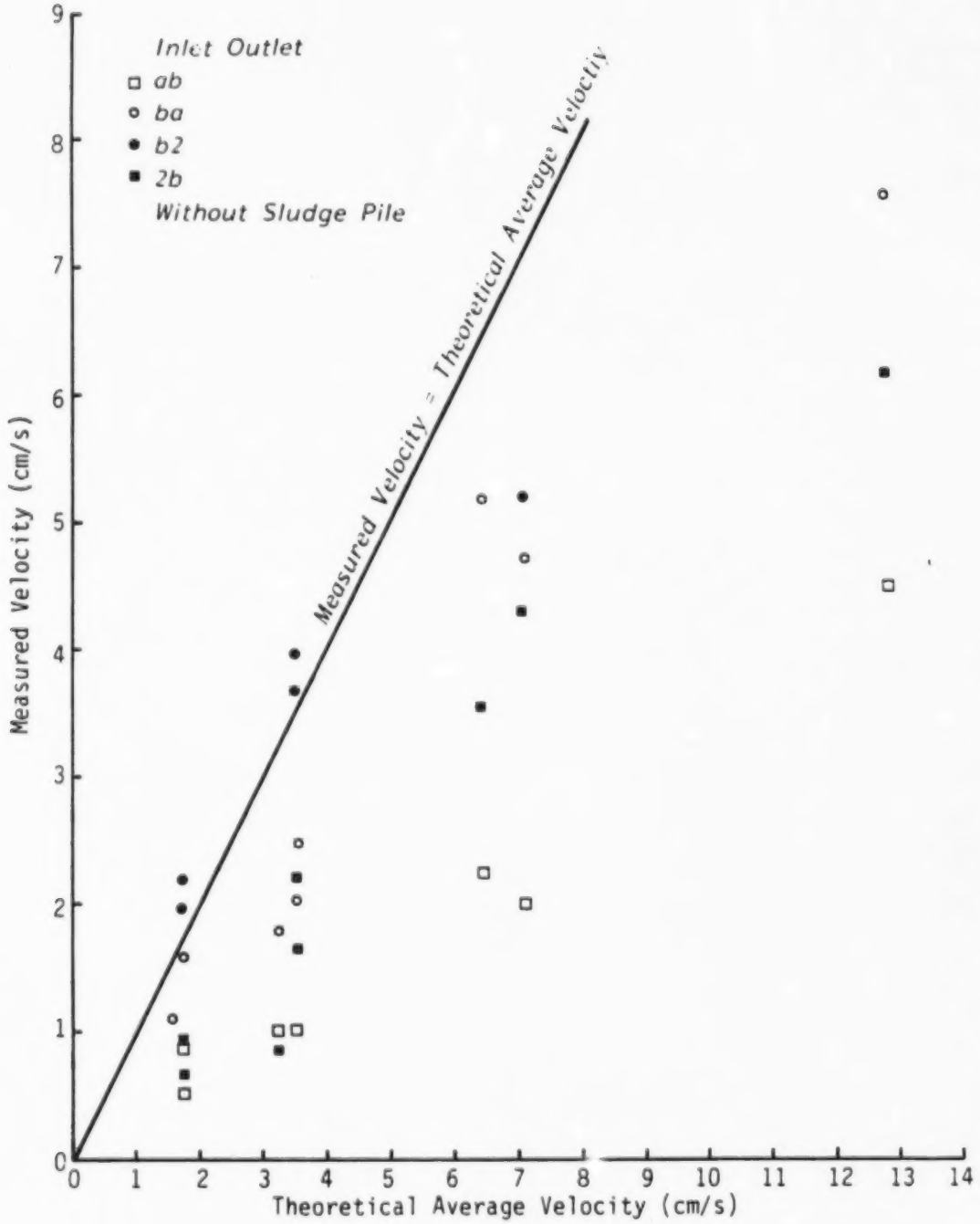


FIGURE 13

VARIATION OF VELOCITY WITH THEORETICAL 'AVERAGE' VELOCITY

Above a theoretical average velocity of 4 cm/s, the "BA" and "B2" configurations appear to give similar results. The "B2" configuration requires that the other peripheral blowdowns be blocked off from the solvent flow. If this is not feasible or if cavitation is a problem, then the "BA" configuration could be used especially if the flowrate is such that the theoretical "average" velocity will be 4 cm/s or greater.

d. Flowrate

Although the highest possible flowrate through the steam generator would be desirable from the point of view of solvent effectiveness, other considerations will place limits on the maximum and minimum acceptable values. The optimum flowrate appears to be the highest possible flowrate subject to equipment limitations. For example, erosion-corrosion in the blowdowns may be a concern. It is being addressed in other studies/8/. The tests showed problems with cavitation in the outlet blowdowns for the B2 configuration at flowrates greater than 3 L/s at water levels less than 15 cm. This places a limit on the minimum acceptable water level and maximum allowable flowrate.

e. Effect of Sludge Pile

Figure 14 compares velocities measured in the presence of the simulated sludge pile to theoretical average velocities for various inlet/outlet configurations. The measured velocities were calculated from transient times across the tube bundle as shown in Figure 10. The maximum height of the sludge pile in the tube lanes used for measuring velocity was 50 mm. Theoretical average velocities were calculated as before neglecting any effects of the sludge pile. The flowrates and water levels were 1.5 - 5.42 L/s and 7.7 - 15.3 cm respectively. Measured velocities were less than the corresponding theoretical average velocities in all cases. The ratio of measured velocity to theoretical average velocity was the lowest at the highest theoretical average velocity. This occurred at the minimum water level (7.7 cm) and showed that there was some preferential flow around the sludge pile rather than over it.

The measured velocity most closely approached the theoretical average velocity at a latter velocity of 3.6 cm/s. This occurred with the B2 configuration. Cavitation problems prevented any comparison with higher theoretical average velocities at this configuration.

The presence of a sludge pile as configured in these tests appears to decrease the fraction of flow across the sludge pile at theoretical average velocities above 4 cm/s. Below 4 cm/s, measured velocities in the BA and 2B configurations appear comparable to those in tests conducted without a sludge pile (Figure 13).

f. Optimum Water Level

The optimum water level for a chemical clean is the level at which the velocity across the sludge pile is maximized using the optimum configuration. This velocity depends on the flowrate and water level. Cavitation problems

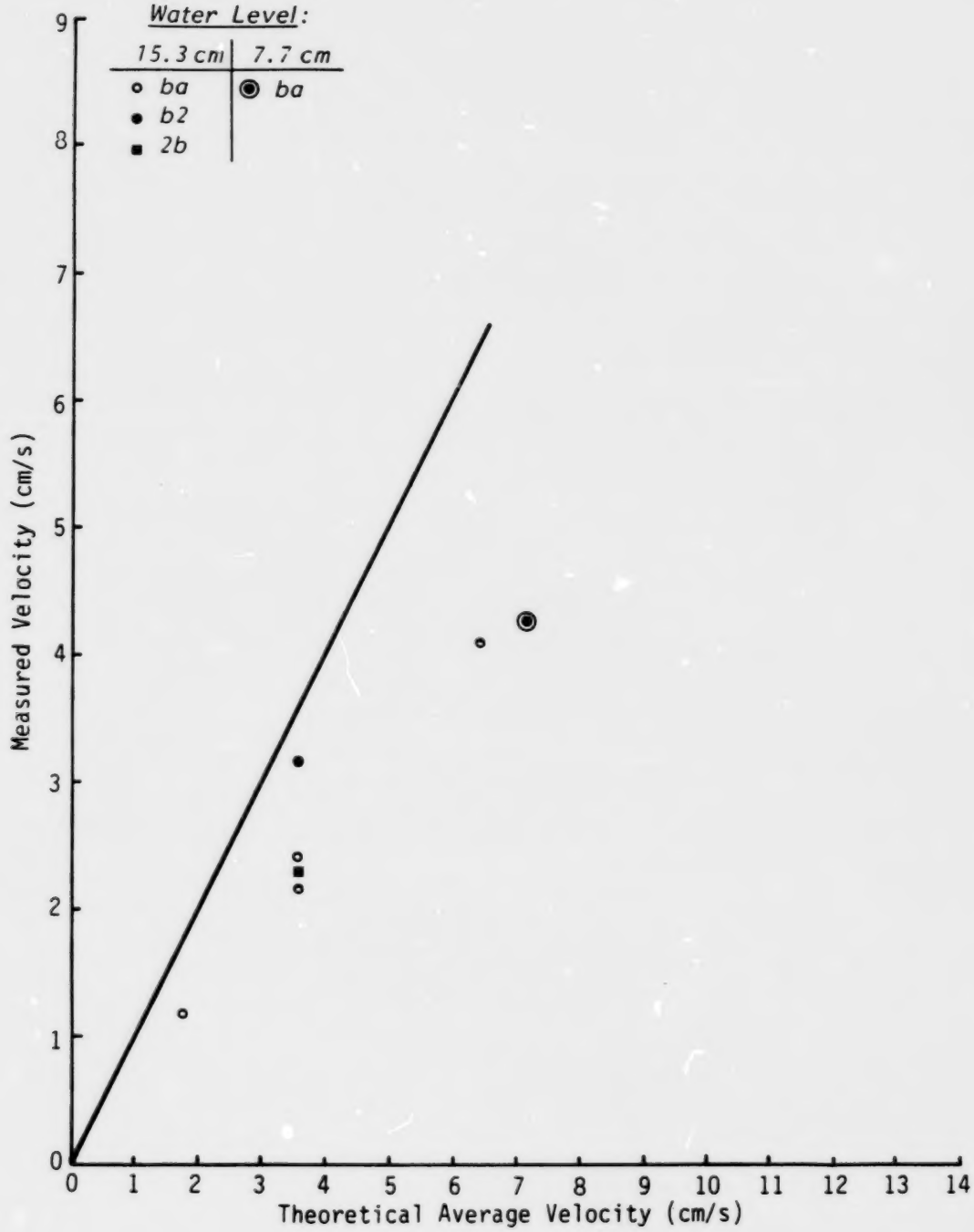


FIGURE 14

VARIATION OF VELOCITY OVER SLUDGE PILE
WITH THEORETICAL 'AVERAGE' VELOCITY

were encountered at low water levels at high flowrates. The flowrate appeared to be the limiting factor. Therefore, since the flowrate is restricted, the velocity can be maximized only by decreasing the water level. However, the sludge pile must be submerged and thus limits the minimum water level. Therefore, the optimum depth of the solvent appears to be the minimum depth such that the sludge pile is still submerged.

6.3 Comparison Between Millstone 2 and Bruce "A"

Two Millstone 2 steam generators were chemically cleaned in May of 1985/6,7/. The initial height of the sludge pile was estimated at 33 cm maximum. This clean was reported to be successful and so would provide a good basis for comparison with the proposed process for cleaning Bruce steam generators. Relevant parameters for comparing the chemical cleans at the two stations are listed in Table 2.

TABLE 2

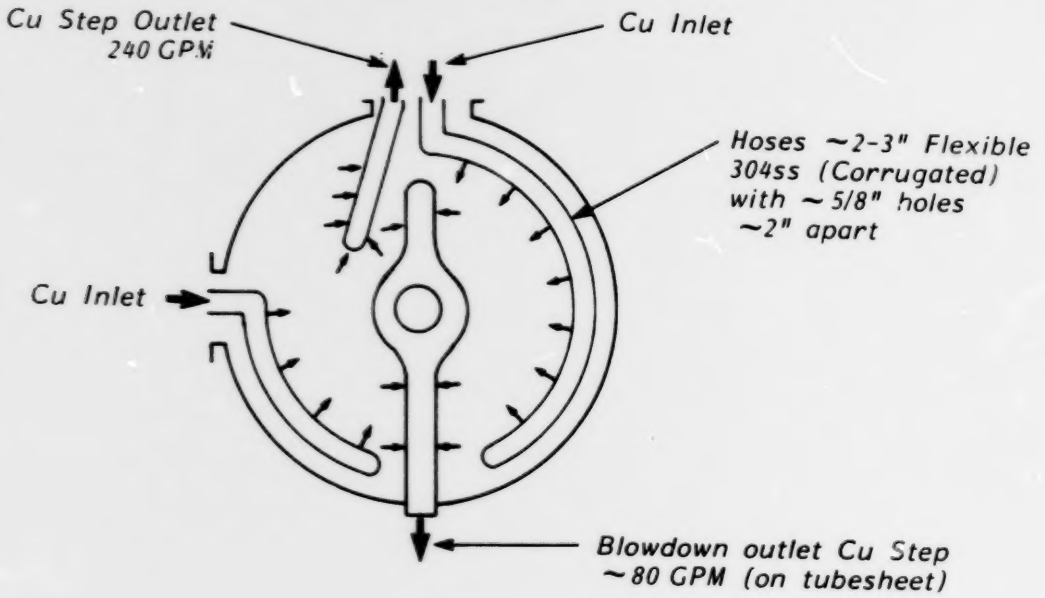
Comparison between Millstone 2 and Bruce "A"

	Millstone 2	Bruce "A"
Steam Generator Diameter	approx. 370 cm	221 cm
Tube Bundle Diameter	approx. 300 cm	198 cm
Tube Diameter	1.91 cm	1.27 cm
Tube Pitch and Spacing	square	triangular 20.32 mm
Solvent Depth	45 cm	20 cm (estimate)
Volume solvent in SG	2587 L	383 L (estimate)
Flow Rate Fe Step Cu Step	12.6 L/s 21.4 L/s	8.8 L/s (estimate) " "
Solvent Residence Time in steam generator	120 s(Cu step) 205 s(Fe step)	44s (estimate)
Solvent Velocity * in steam generator	0.75 cm/s(Fe) 1.28 cm/s(Cu)	4 cm/s(experimental)

* Calculated neglecting any effect of sludge pile. The configuration used at Millstone differed from that which could be used at Bruce "A" (see Figure 15). For comparison, it is assumed that the configurations are similar.

Millstone 2 Chemical Clean Flow Through Steam Generators

1. During Cu Removal (320-400 GPM to keep T within specs)



2. During Fe Removal (200 GPM)

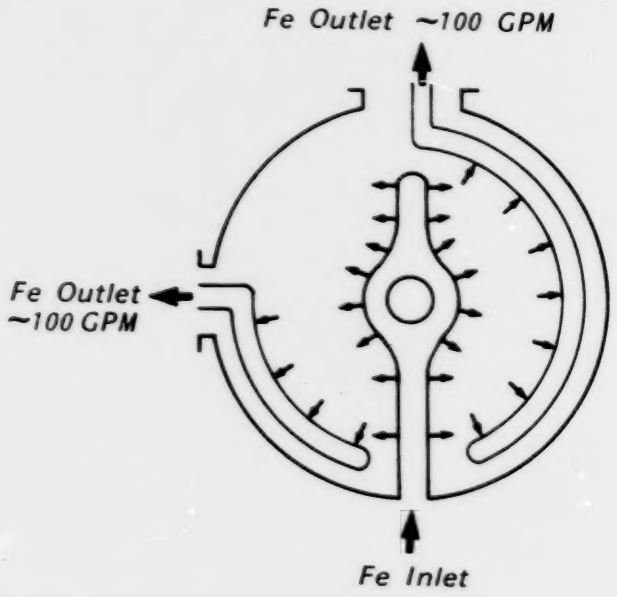


FIGURE 15

SOLVENT INLET/OUTLET CONFIGURATION AT MILLSTONE 2

It is apparent from Table 2 that the velocities over the sludge pile would be greater at Bruce than at Millstone 2. The inlet/outlet configuration at Millstone (Figure 15) was different from (and apparently less favourable than) that planned for Bruce. The Bruce "BA" and "B2" configurations ensure flow across the entire tubesheet while the configurations used at Millstone 2 left one quadrant of the steam generator with little if any flow.

7. CONCLUSIONS AND RECOMMENDATIONS

1. The Fill/Drain method of circulating solvent over the sludge pile does not ensure good flow over the sludge pile.

2. The Recirculation method of circulating solvent over the sludge pile can ensure good flow over the sludge pile. The following parameters were optimized for a steam generator chemical clean:

a. Optimum Inlet/Outlet Configuration

The optimum inlet/outlet configuration uses the boxheader as the solvent inlet to the steam generator and the two peripheral blowdowns farthest from the boxheader on each side of the box header as outlets. Isolation of the other peripheral blowdowns to prevent solvent flow through them is necessary. If this is not feasible, either because isolation is impossible, or cavitation in the outlet blowdowns is likely, then it is recommended that all peripheral blowdowns be used as solvent outlets.

b. Optimum Water Level

The optimum water level in the steam generator is the minimum level at which the sludge pile remains submerged. The depth should be increased however to build in a margin of assurance. For a 15 cm sludge pile, a 20 cm solvent depth is suggested. The minimum water level is limited by cavitation at the outlet blowdowns which was observed at solvent depths of less than 15 cm for a flowrate greater than 3 L/s with the B2 configuration.

c. Optimum Flowrate

The optimum flowrate appears to be the highest possible flowrate given equipment limitations and any limitations on flow defined by erosion-corrosion tests/8/. A flowrate of 6 to 11 L/s would be sufficient. At a solvent level in the steam generator of 20 cm, a minimum flowrate of 8.8 L/s is recommended if all peripheral blowdowns must be used as outlets.

8. SUMMARY

Tests in the Flow Visualization Loop effectively demonstrated flows through the tube bundle during a physical simulation of a chemical clean. Solvent recirculation was superior to fill/drain for maximizing flow over the sludge pile. It is possible to get good solvent circulation over the sludge pile using the blowdown lines as inlets and outlets.

The inlet/outlet configurations in decreasing order of effectiveness were; boxheader as inlet and the two peripheral blow downs farthest from the boxheader as outlets; all peripheral blowdowns as outlets and the boxheader as the inlet; and all peripheral blowdowns as inlets and the boxheader as the outlet.

The optimum depth was identified as the minimum depth for which the sludge pile remained submerged, allowing for some margin of assurance. The optimum flow rate was identified as the highest flowrate feasible with respect to engineering constraints.

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